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PHYSIOLOGIC RESPONSE TO TRANSIENT HEAT STRESS IN REFLECTIVE VERSUS NONREFLECTIVE CLOTHING

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6570th AEROSPACE MEDICAL RESEARCH LABORATORIES
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Project No. 7222, Task No. 722204

NOTICES

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Aerospace Medical Division, 6570th
Aerospace Medical Research Laboratories,
Wright-Patterson Air Force Base, Ohio.
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Six subjects wearing either nonreflective or reflective outer garments of equal insulative value (1 clo) and unventilated were exposed in 96 experiments to heat pulses of 93°, 121°, 149°, and 177° C for 15, 12, 9, and 2 minutes, respectively. The experiments were designed to simulate a range of re-entry heat exposures produced by malfunction or failure of the air-conditioning system of the vehicle. Total experimental time included

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2. Thermal Stresses
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4. Reflective Clothing
5. Protective Clothing
I. AFSC Project 7222, Task 722204
II. Biomedical Laboratory
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FOREWORD

This research study was initiated in May 1962 by the Biomedical Laboratory, 6570th Aerospace Medical Research Laboratories, and was terminated in March 1963. This report represents one phase of the research programs being conducted by the Biothermal Branch, Physiology Division, Biomedical Laboratory, under Project 7222, "Biophysics of Flight," Task 722204, "Human Thermal Stress."

The authors acknowledge with thanks the services of the Analytical Branch, Physics Laboratory, Directorate of Materials, Aeronautical Systems Division, in measuring the surface reflectivity of fabrics used in this study.

ABSTRACT

Six subjects wearing either nonreflective or reflective outer garments of equal insulative value (1 clo) and unventilated were exposed in 96 experiments to heat pulses of 93°, 121°, 149°, and 177° C for 15, 12, 9, and 2 minutes, respectively. The experiments were designed to simulate a range of re-entry heat exposures produced by malfunction or failure of the air-conditioning system of the vehicle. Total experimental time included the heat pulse and subsequent recovery period and was constant (40 minutes) for all conditions. Mean weighted skin and rectal temperatures, heart rate, total sweat produced and evaporated, and cardiac output, indirectly derived from blood pressure measurements, were the observed physiologic parameters. Evaluation of each parameter, individually, indicates that for some there is no relation between the physiologic response, the type of garment protection, and the level of thermal stress, while for others there is marginal benefit derived from wearing aluminized outer clothing. At only one time-intensity profile did the physiologic penalty of wearing nonreflective outer clothing appear more than marginal. However, even under the most severe conditions of thermal stress and absence of reflective protection, none of the physiologic responses approached tolerance limits in our terms of reference. The thermal protective effectiveness and practicality of the aluminized outer garment for intravehicular aerospace flights is also discussed.

PUBLICATION REVIEW

This technical documentary report is approved.

Jos M Quashnock

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Colonel, USAF, MC
Chief, Biomedical Laboratory

PHYSIOLOGIC RESPONSE TO TRANSIENT HEAT STRESS IN REFLECTIVE VERSUS NONREFLECTIVE CLOTHING

by

A.T. Kissen, Ph.D.

and

J.F. Hall, Jr.

INTRODUCTION

Thermal protection of humans exposed to severe heat exposure, as in fire fighting or, more recently, for protection of astronauts during re-entry phases of aerospace flights, has resulted in widespread use of infrared-reflective-surface-type clothing. Research to develop a heat-reflecting, fire-fighting clothing assembly was initiated by the Air Force as early as 1946 (refs. 5, 13). It was early recognized that a highly polished metallic surface possessing necessary high-temperature characteristics would be useful. Of those commercially available, aluminum proved most feasible. As early as 1949 suits made of aluminum-coated asbestos on fiberglas cloth were experimentally fabricated and successfully tested at Wright-Patterson Air Force Base for aircraft fire-fighting purposes. By 1952 both aluminized cotton and aluminized asbestos-fiberglas type assemblies were available. On the basis of better abrasion resistance, lighter weight, and improved drape or fitting properties, the aluminized asbestos-fiberglas material was selected.

Using reflective clothing for thermally protecting the aerospace crew member from re-entry heat loads, or from heat stress resulting from emergency failure of air-conditioning systems, is a more recent application. In the event of failure of air conditioning during re-entry of a boost glide vehicle, Kordenbrock (ref. 8) predicted wall temperature increases of 21.1° C/minute until 260° C was reached. Carter and Bell (ref. 3) predicted wall temperature increases of 15.6° C/minute to a peak of 427° C. These predictions thus define the critical need for thermal protection of aerospace flight crews. Some human heat tolerance data in the range from 21.1° to 260° C for subjects wearing both nonventilated and ventilated aluminized clothing was reported by Webb (refs. 11, 12). This data was obtained partially with the 6570th Aerospace Medical Research Laboratories heat pulse facility (ref. 4) and with a facility installed at the Firewel Company.* In the latter heat chamber, rate of wall heating was lower and neither front nor back walls were heated. On the basis of a pain-tolerance (intolerable pain) limit, the test results indicated best protection was afforded by the aluminized coverall assembly even when no ventilation was used.

*Buffalo, New York

However, comparative data obtained from subjects wearing quantitatively equivalent insulation (as measured on copper physical models) of both reflective and nonreflective clothing at various severe and constant exposure levels—93° C (200° F), 121° C (250° F), 149° C (300° F), and 177° C (350° F)—as conducted in this report was not previously available. Aluminized or metallic-coated cloth surfaces having the desired reflectivity to radiant heat are unfortunately practically impermeable to water vapor. Consequently, while radiative heat loads may be reduced by wearing such suits, evaporative heat loss in nonventilated exposure conditions may be seriously reduced.

We performed the experimental studies described in this report on nonventilated, "shirtsleeve" (1 clo), sitting-resting subjects to determine the relative total physiologic protection provided by wearing nonreflective as compared with reflective insulation during exposures to severe heat stress. These results should be useful in determining actual requirements for and effectiveness of reflective suits for thermal protection against slow heat pulses having time-temperature relationships as described in this report.

PROCEDURE

We conducted 96 experiments on 6 healthy, nonacclimatized male subjects whose physical characteristics are shown in table 1. Each sitting-resting subject wearing 1 clo total insulation was exposed 4 times to each of the 4 heat pulse profiles, twice while wearing a nonreflective assembly and twice while wearing the reflective, aluminized assembly. Total insulation, as well as that covering body, hands, feet, and head was precisely measured on copper physical models prior to the experimental exposures. In table 2 the measured thermal insulation values for both types of assemblies are presented. No insulation covered the face. Clothing worn consisted of the thermistor underwear suit plus the respective reflective or nonreflective suit assembly items (i.e., coverall, gloves, boots, socks, and helmet). Time-temperature relationships for each of the heat stress exposures studied are schematically shown in figure 1. Wall temperatures were increased at a rate of 82° C/minute to levels of 93°, 121°, 139°, and 177° C and maintained for 15, 12, 9, and 2 minutes, respectively, at these temperatures. Air temperature increase was passive in type due to natural convection within this test facility. At the conclusion of each heat pulse, wall heating was stopped and passive cooling of walls and air occurred. During the recovery period the chamber door was kept closed until air temperatures reached 66° C.

Previous measurements (ref. 4) of the radiantly heated inner wall surfaces showed a mean emissivity of 0.76 between 38° and 370° C. Relative reflectivity of both the nonreflective and reflective fabric surfaces was measured both prior to and following these experimental tests. These measurements indicated an approximate one-third loss of spectral reflectivity occurred with the aluminized suit, presumably due to abrasive wear and oxidation during heat exposure. Significant change in reflectivity value of the nonreflective suit did not occur. Original emissivity values (calculated) for these reflective and nonreflective suits were 0.3 and 0.9, respectively.

TABLE 1

PHYSICAL CHARACTERISTICS OF SUBJECTS

Subject	Age	Occupation	Height (in.)	Weight (kg.)	Surface Area (m^2)
A	42	Airman	69	69.0	1.84
B	33	Project Officer	70	89.0	2.07
C	21	Airman	72	72.2	1.93
D	31	Medical Officer	73	118.0	2.41
E	33	Project Officer	65	64.5	1.71
F	28	Airman	69	67.5	1.82

TABLE 2

THERMAL INSULATION OF CLOTHING WORN

	Total*	Body+	Hands	Feet	Head
Nonreflective (K-2B)	0.96	1.48	0.85	1.33	0.95
Reflective (Aluminum)	0.99	1.73	0.90	1.19	0.98

*expressed in clo units
+includes arms, legs, and trunk regions

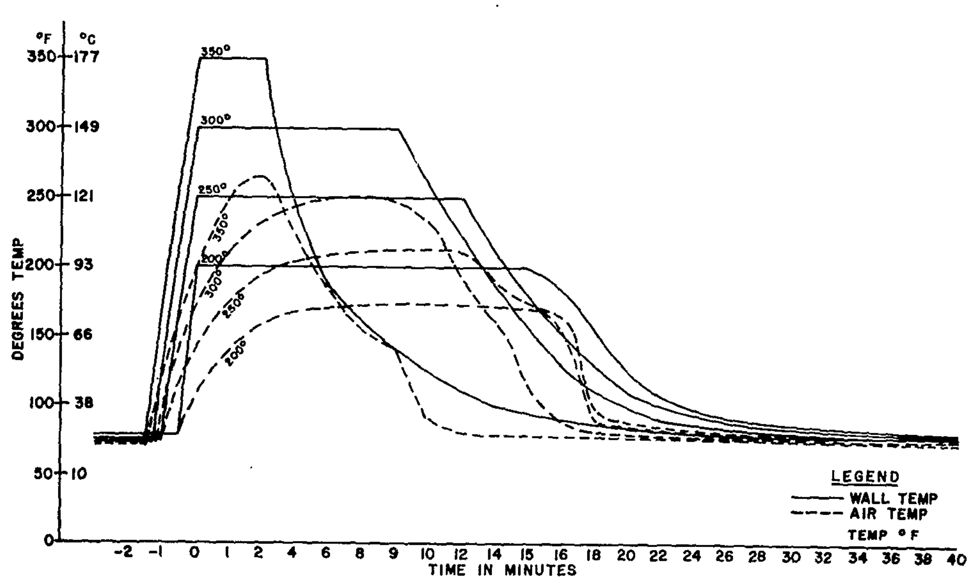

Figure 1. Time-Intensity Profiles, Mean Wall and Mean Air Temperatures Versus Time

Physiologic measurements were continued until a total experimental time (including the heat pulse period, per se) of 40 minutes had elapsed. Heart, sweat, and rectal temperature rate changes were recorded with electrocardiogram, nude pre- and post-experimental body weighings, and a rectal thermistor, respectively. Skin temperatures were continuously measured with 17 thermistors and weighted mean skin and body temperatures determined by Burton's method (ref. 2). Evaporative rate was obtained from pre- and post-experimental clothed weighings and percentages of sweat evaporated expressed as a sweat-evaporative rate ratio. Body weighings were made with a precision platform-type balance accurate to ±4 gm. Skin temperatures were accurate to ±0.2° C and rectal temperatures to ±0.1° C. Prior to each heat pulse exposure, control levels for skin and rectal temperatures, heart rate, and blood pressure were determined with the subject exposed to a comfort environment (21° to 24° C).

Arterial systolic and diastolic blood pressures were indirectly measured at 3-minute intervals throughout the experiment by means of an automatic system utilizing a brachial artery microphonic pick-up (ref. 7) developed by Systems Research Laboratories, Inc.* Based on nomographic data presented by Jackson (ref. 6), blood pressure measurements were used for calculation of cardiac outputs. Validity of estimating cardiac output and stroke volume from blood pressures or pulse pressure was examined carefully by Starr and associated (refs. 9, 10), whose results are discussed later in this paper.

RESULTS

Mean Skin Temperature

The relative elevations of mean skin temperature of all subjects in response to the various time-intensity heat profiles are shown in figure 2. Minimal stress in terms of this parameter was experienced by subjects clothed in reflective outer garments and exposed to the 15-minute, 93° C profile. Under these conditions, mean skin temperature peaked at 16 minutes (1 minute after the wall heating elements were turned off) at 5.1° C above the mean control skin temperatures. Maximal elevation of mean skin temperatures was experienced by subjects clothed in nonreflective outer garments and exposed to the 9-minute, 149° C profile. The mean skin temperature peaked in 10 minutes—again 1 minute after deactivation of heating elements—at 9.5° C above the mean control skin temperatures. Analyses of variance were performed to test the significance of mean skin temperature differences attributable to clothing, at various time intervals. For each profile the mean skin temperature data was treated statistically at the following points in time: (a) at the conclusion of the sustained period of maximal wall temperature, (b) at peak skin temperature, and (c) 20 minutes after the onset of the heat pulse. Finally, data obtained at the conclusion of the entire exposure-recovery period (40 minutes) was similarly tested for significance. Analyses of variance performed on mean skin temperature change indicate that for each profile the aluminized garment offers statistically significant protection in terms of lower mean skin temperature for all time intervals examined except two.

* Dayton, Ohio

These exceptions were found at the conclusion (40 minutes) of the 15-minute, 93° C profile and 2-minute, 177° C profile, when no difference in mean skin temperature exists. Maximal benefit derived from the aluminized outer garment was observed during the last 2 minutes of the 9-minute, 149° C profile where a mean skin temperature differential of 1.3° C was measured between the two clothing assemblies.

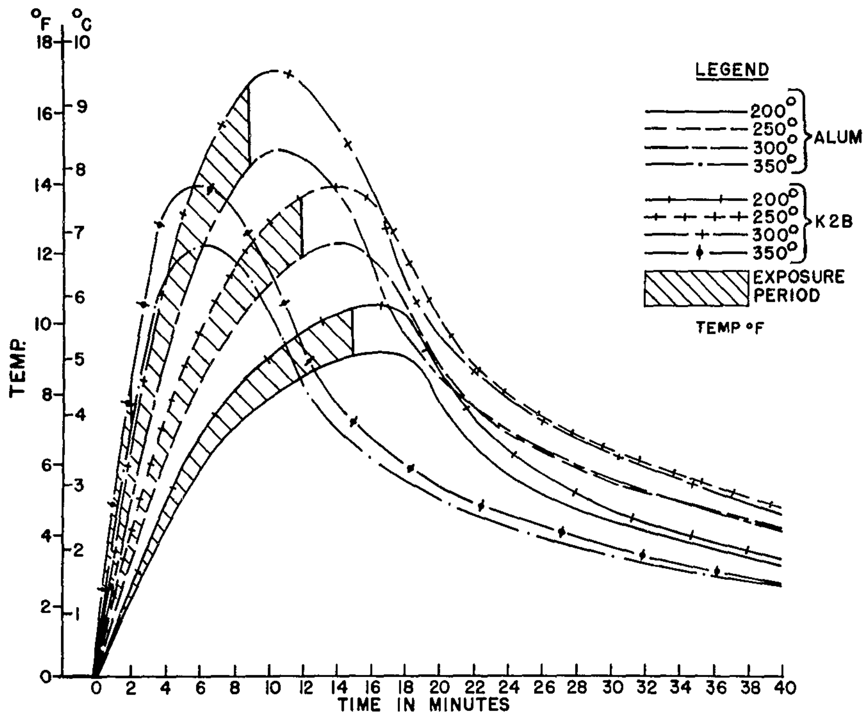

Figure 2. Change of Mean Skin Temperatures for the Various Time-Intensity Profile and Clothing Assembly Combinations Versus Time

Mean Rectal Temperature

The response of rectal temperature to each profile is shown in figure 3. Without exception all rectal temperature curves describe a paradoxical decrease as an immediate response to the heat pulses. While the magnitude of this fall in rectal temperature does not exceed 0.05° C, it is evident in virtually all exposures and is interpreted as an indication of blood shift. Minimal rectal temperature elevations of approximately 0.2° C were experienced by those subjects exposed to the 2-minute, 177° C profile, wearing either of the clothing assemblies, and to the 15-minute, 93° C profile, wearing nonreflective clothing. The rectal temperature curve of subjects wearing reflective clothing, exposed to the 15-minute, 93° C profile, did not describe any decrease in value throughout the recovery period, but merely a reduction in the rate of increase. Maximal rectal temperature change was demonstrated during the recovery phase of the 9-minute, 149° C profile. Here, peak rectal temperature changes of 0.67° C and 0.59° C with nonreflective and reflective clothing, respectively, were reached approximately 18 minutes after the end of the heat pulse. The rate of rectal temperature rise for both clothing assemblies was identical. However, in the case of reflective garment protection, the rectal temperature peaked at a value approximately 0.1° C below that for subjects in the nonreflective garment.

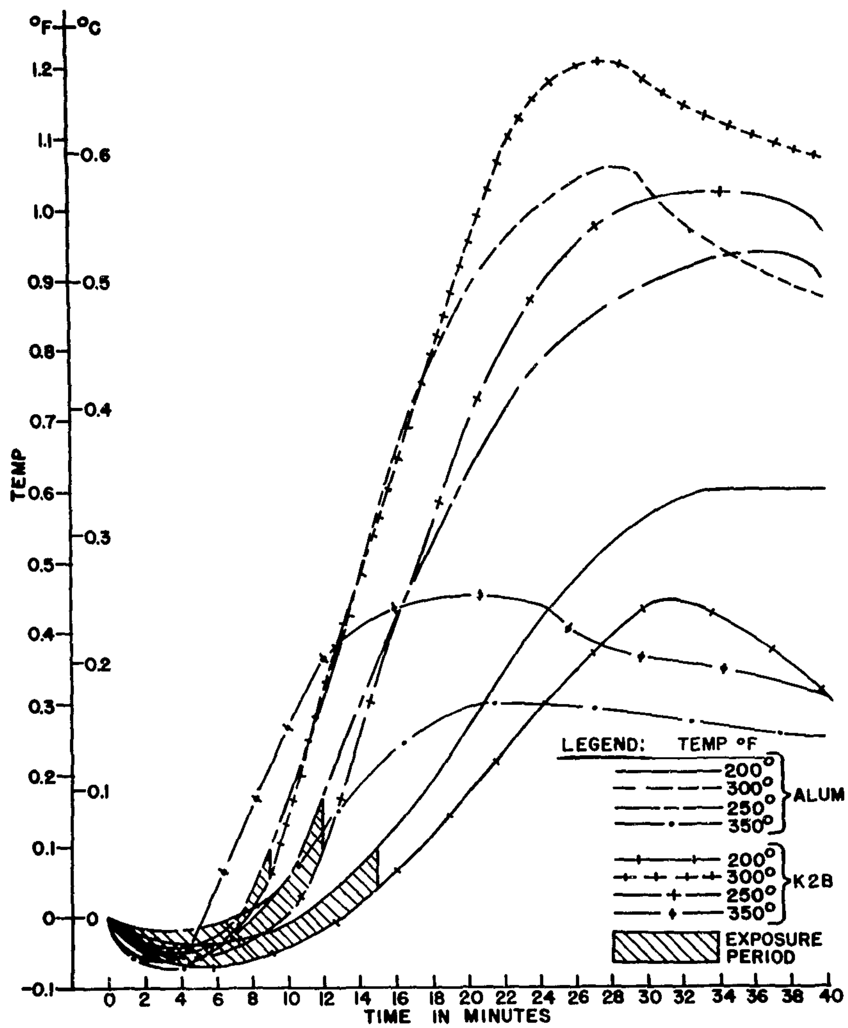

Figure 3. Change of Mean Rectal Temperatures for the Various Time-Intensity Profile and Clothing Assembly Combinations Versus Time

Mean Cardiac Output

Increase in cardiac output over control values for each pulse profile and clothing assembly is shown in figure 4. There appears to be a subdivision of these values into relatively high and low cardiac outputs with the change in output of 3.1 liters/minute, approximating a 75% increase, being the point of division. The three profile-suit conditions of the high-output group are the 12-minute, 121° C profile (nonreflective garment), and the 9-minute, 149° C profile (both garment types). Output values attained under these profile-suit conditions represent an 80% to 100% increase in cardiac output over control values. There is a sharp decrease in cardiac output with aluminized protection for the 12-minute, 121° C profile.

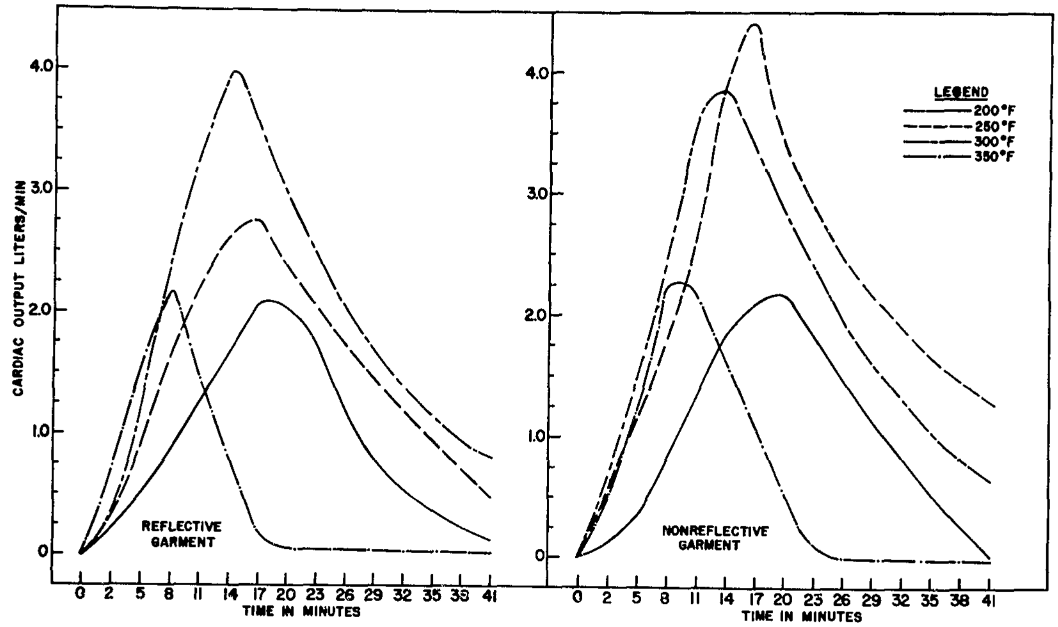

Figure 4. Change of Mean Cardiac Output for the Various Time-Intensity Profile and Clothing Assembly Combinations Versus Time

All remaining time-intensity heat pulses and clothing assembly combinations contribute to approximately 50% increase in cardiac output. Analyses of variance were performed within each time-intensity heat pulse situation to determine the significance of differences attributable to the type of clothing assembly. The only instance in which statistical significance in cardiac output differences could be associated with clothing assembly was in the 12-minute, 121° C profile. The subjects clothed in reflective garments experienced significantly lower cardiac output increases as compared to their experience in the same pulse exposure clothed in the nonreflective assembly.

Mean Heart Rate

Cardiac performance in terms of increase in heart rate in response to various heat pulses is shown in figure 5. As in the case of cardiac output, the curves describing heart rate increase over control values appear to fall into two groups with the line of division being a heart rate increase of 35 beats per minute or approximately a 50% increase over the control. The group exhibiting the greatest response, as in the case of cardiac output, is comprised of the 9-minute, 149° C profile (with either clothing assembly) and the 12-minute, 121° C profile (with nonreflective clothing). Maximum increase in heart rate (49 beats per minute) is produced by the 9-minute, 149° C profile (with nonreflective clothing). The 12-minute, 121° C profile (nonreflective clothing) and 9-minute, 149° C profile (reflective clothing) produce increases in heart rate slightly lower but within about 10 beats per minute of the maximum. The remaining time-intensity profile and clothing assembly combinations yield heart rate increases between 21 and 32 beats per minute with the lowest value produced by the 2-minute, 177° C profile with aluminized outer clothing.

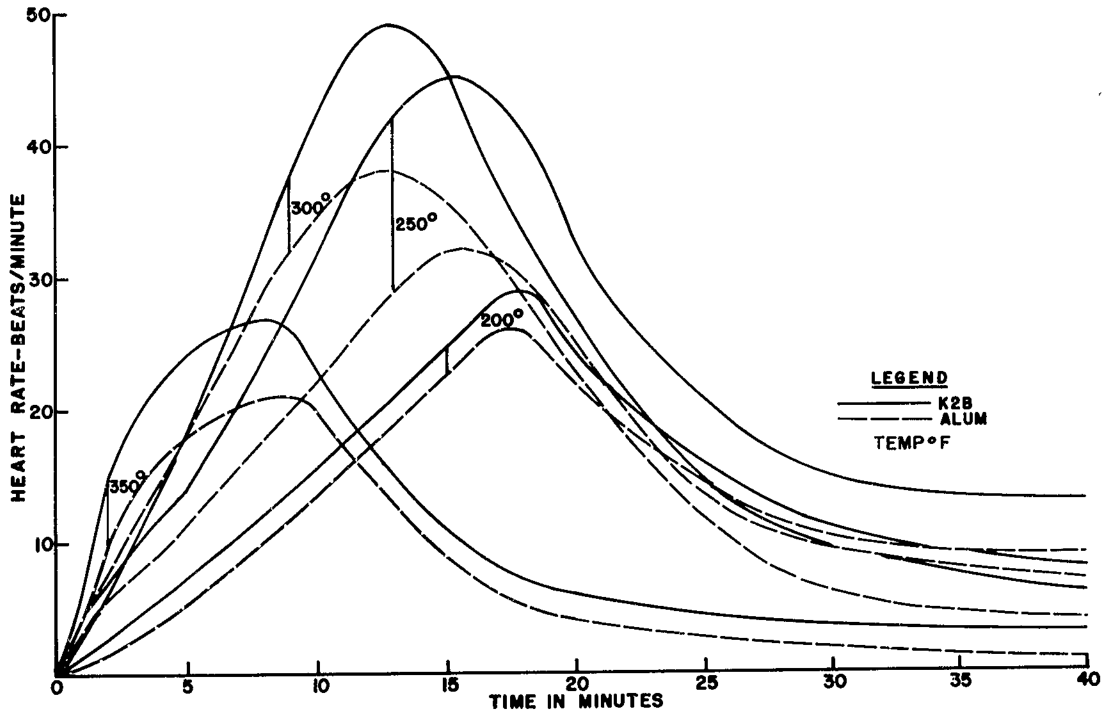

Figure 5. Change of Mean Heart Rate for the Various Time-Intensity Profile and Clothing Assembly Combinations Versus Time

Sweat Production

There is a direct and consistent relationship between the time-intensity profile and protective clothing assembly combination and the total sweat production. Figure 6 illustrates the extent of total sweat production, sweat evaporation, and the relationship of these values in terms of the evaporative-sweat ratio. Mean values are presented in terms of grams per square meter for each of the thermal exposures. An overall appraisal indicates that for any time-intensity profile considered sweat production (as well as sweat evaporation) is greater in the nonreflective garment. The increase of total sweat produced for all time-intensity profiles ranged from 20 to 40 grams/sq. meter. Increased sweat evaporation ranged from 10 to 30 grams/sq. meter. Maximum sweat production and evaporation occurred in nonreflective-clothed subjects exposed to a 9-minute, 149° C profile. Both values decreased over the 12-minute, 121° C and 15-minute, 93° C profile for similarly clothed subjects. However, the lowest values were still above corresponding figures for subjects clothed in reflective garments. The amount of sweat produced and evaporated associated with the 2-minute, 177° C profile appears strongly time dependent and should be considered separately.

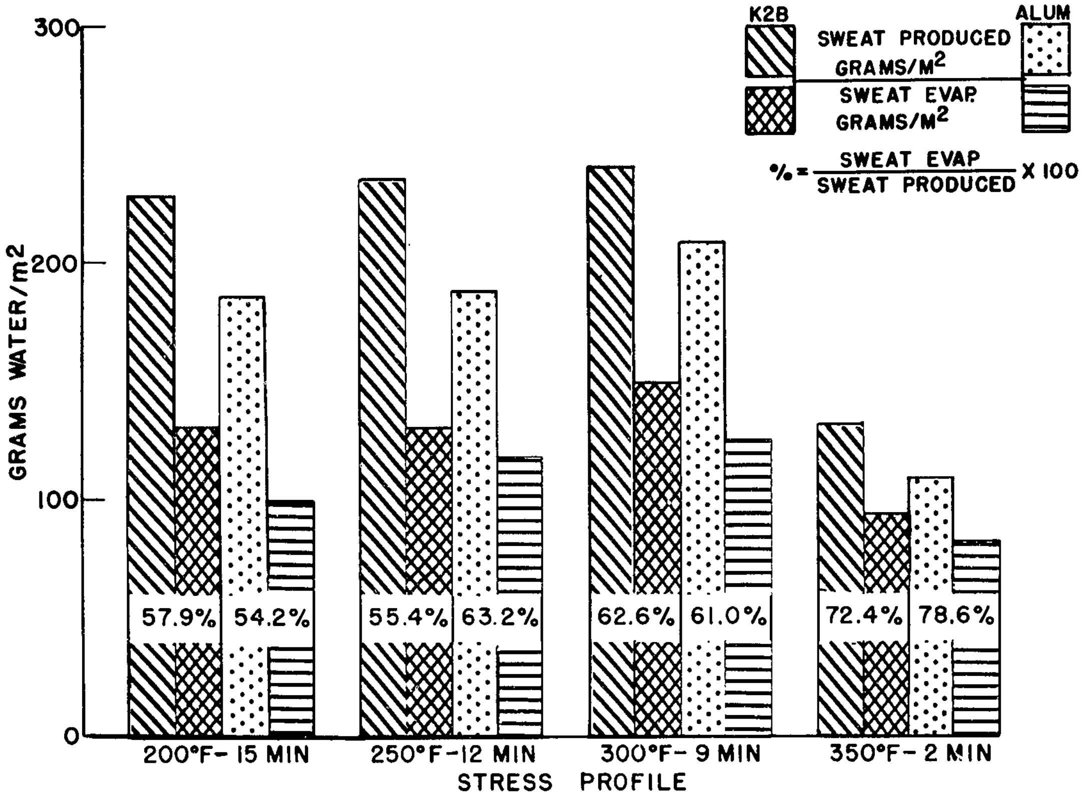

Figure 6. Total Sweat Production, Sweat Evaporation, and Sweat-Evaporation Ratio for the Various Time-Intensity Profile and Clothing Assembly Combinations

DISCUSSION

A theoretically sound, quantitative method for the evaluation of physiologic strain produced by exposure to thermal stress has yet to be developed. Even in so-called steady-state exposure, where equilibrium of air and wall temperatures has been achieved, precluding the necessity of separate consideration of radiative and convective heat transfer, other problems exist. These involve, chiefly, proper assessment of the subject's responses. All of these problems are intensified when the thermal stress is produced by extreme, transient heat pulses of various intensities and durations. The experiments described are composed of four such time-intensity heat pulse exposures. The selection of intensities was designed to encompass a range of re-entry wall and air temperatures resulting from air-conditioning malfunction or failure. The failure of such a system would permit the cabin air to follow the inner wall temperatures in a passive, uncontrolled manner. Duration of exposure to each temperature level was designed to severely stress the subject. Exposure durations for the thermal levels of 93°, 121°, 149°, and 177° C were 15, 12, 9, and 2 minutes, respectively. Time extensions beyond these limits would compromise the performance of the subject by virtue of physiologic decompensation, or intolerable pain.

Our attempt to evaluate the magnitude of physiologic strain produced by such time-intensity profiles is based upon five monitored parameters: skin and rectal temperatures, heart rate, cardiac output, and total sweat production. Under other circumstances body heat storage in terms of calories per square meter would receive equivalent consideration. However, because of the transient nature of the stress and the lag characteristics of rectal temperature change upon which heat storage calculations depend, we decided to ignore this parameter. Skin and rectal temperatures, heart rate, and total sweat production are based upon direct thermistor, electrocardiograph, and precision balance measurements, respectively. Our cardiac output measurement on the other hand is indirect and warrants some discussion. For obvious reasons, none of which relate to its validity, the direct measurement of cardiac output involving vascular catheterization presents severe limitations to routine investigations of this nature. We are able to obtain, indirectly, both systolic and diastolic blood pressures. The instrument for this purpose automatically provides for alternate occlusion and patency of an artery (in this case, the brachial) and a microphone pick-up of the presence of arterial sounds. The two sensing elements for pressure and sound are incorporated into the pressure-cuff system. The readings are amplified and sensed by a small transistor computer which performs the same general, logical steps as the clinical blood pressure measurement. The signal output of the instrument is in the form of voltage pulses which are proportional to the diastolic and systolic pressures. This procedure of blood pressure measurement in contrast to direct measurements may be subject to the criticism that its dependency is upon lateral rather than end pressure detection.

The relationship of pulse pressure and age to cardiac stroke volume has been investigated by Starr (refs. 9, 10). The method involves appropriate weighting of systolic, diastolic, and age values. Starr applied this technique to data derived by other investigators who had determined cardiac outputs by direct methods. His results indicate good correlation and encouraged Jackson (ref. 6) to construct a nomogram for the simple calculation of cardiac output. We found the nomogram procedure lacking in desired precision and resorted to machine calculation of the stroke volume and cardiac outputs. In a separate series of unpublished studies* we had the opportunity to compare estimations of cardiac output derived by the indirect method described above with simultaneously derived cardiac outputs using the dye-dilution technique. Although our findings indicated a statistically significant correlation between the two sets of derived output values we must admit to discrepancies in terms of absolute values. Cardiac output values obtained through use of the indirect blood pressure determination were almost always lower than corresponding values obtained by the dye-dilution technique. We are presently attempting to determine if this discrepancy is due to deficiencies in instrumentation or if it is simply a function of differences of methods. However, the good correlation of the sets of values over a range of cardiac output changes encouraged us to include this data in describing the extent of cardiac output change for the various time-intensity profile and clothing assembly combinations.

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*Performed in the 6570th Aerospace Medical Research Laboratories

On the basis of the parameters examined there is, in general, some evidence of physiologic strain reduction for those subjects clothed in reflective outer garments. We feel obligated, however, to qualify the extent and significance of this reduction. Data relative to skin and rectal temperature change generally indicates greater dependency of these responses upon the level of stress than upon the nature of clothing assembly worn during any particular stress exposure. Even where statistical significance of mean skin temperature disparity relative to garment type was demonstrated, this difference did not exceed 1.5° C and maximum temperature achieved in this instance was 43° C. In the most severe thermal stress the mean rectal temperature rise was negligible, less than 0.7° C, and, at most, 0.1° C above the counterpart exposure with the aluminized garment.

Consideration of heart rate and cardiac output can be reasonably restricted to the 12-minute, 121° C and 9-minute, 149° C time-intensity profile (ref. 1). Neither of these rates achieves as much as 50% increase over control values in the relatively moderate, 15-minute, 93°C and short-term, 2-minute, 177° C profile. Although the maximum mean heart rate change was demonstrated in the nonreflective, 9-minute, 149° C profile, the strongest relationship of heart rate increase to garment assembly was shown in the 12-minute, 149° C profile. Reflection of this can be found in examination of the cardiac output curves. Here, the only time-intensity profile demonstrating significant value differences relative to clothing assembly is the 12-minute, 149° C profile. The unusual cardiac response of this particular profile does not appear to be related to the absolute skin or rectal temperatures attained, since values for these parameters are higher in another time-intensity profile. However, there is an interesting relationship to be found between the heart rate, cardiac output, and evaporative-total sweat (E/S) ratio. Since total experimental time was held constant for all exposures, the E/S ratio is, in a sense, one expression of cooling rate. An examination of this ratio for all profiles and clothing assembly combinations indicates that the greatest difference in cooling rate relative to garment protection is found for the 12-minute, 149° C profile and would appear to be the effect of the relatively low E/S ratio for the nonreflective assembly.

The assessment of physiologic responses to the various levels of thermal stress is expressed as follows. First, there is, considering each physiologic response individually, a variable margin of benefit derived from wearing the aluminized outer garment. While this margin, in some instances, has been shown to be statistically significant, the physiologic advantage is, at best, doubtful. In terms of magnitude of skin and rectal temperature change, heart rate increase, and total sweat produced, the 9-minute, 149° C profile proved to be the most stressful profile with the nonreflective assembly demonstrating marginally poorer protective qualities than the reflective garment. In terms of garment assembly differences, and with specific reference to E/S ratio, change in heart rate, and cardiac output, maximal disparity was demonstrated in the 12-minute, 121° C profile. Here again, the nonreflective exhibited poorer protective capability. However, these tests were conducted on unventilated subjects. If ventilation were provided, proportional differences might still exist but would be of even less significance. This, then, raises the question of the relative effectiveness and merits of the aluminized outer garment under the terms of the thermal stresses imposed here. In determining the merits of the aluminized garment, the cost, the decrement of effectiveness with each wearing

due to abrasion and surface oxidation, and the penalty associated with its impermeability should be considered. There is certainly no intent here to take issue with the effectiveness, or, under the conditions of extravehicular, thermal radiation exposure, the absolute necessity of reflective outer garments. However, until such maneuvers become a reality and for as long as man is expected to remain within the protective confines of his capsule, we should continue to evaluate critically his clothing protection requirements.

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Aerospace Medical Division, 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. Rpt. No. AMRL-TDR-63-79. PHYSIOLOGIC RESPONSE TO TRANSIENT HEAT STRESS IN REFLECTIVE VERSUS NONREFLECTIVE CLOTHING. Final report, Aug 63, iii + 13 pp. incl. illus., tables, 13 refs. Unclassified report

Six subjects wearing either nonreflective or reflective outer garments of equal insulative value (1 clo) and unventilated were exposed in 96 experiments to heat pulses of 93°, 121°, 149°, and 177° C for 15, 12, 9, and 2 minutes, respectively. The experiments were designed to simulate a range of re-entry heat exposures produced by malfunction or failure of the air-conditioning system of the vehicle. Total experimental time included

(over)

UNCLASSIFIED

1. Stress (Physiology)
2. Thermal Stresses
3. Physiology
4. Reflective Clothing
5. Protective Clothing

I. AFSC Project 7222, Task 722204
II. Biomedical Laboratory
III. Kissen, A.T.
IV. Hall, J.F., Jr.
V. In DDC collection
VI. Aval fr OTS: $0.50

UNCLASSIFIED

the heat pulse and subsequent recovery period and was constant (40 minutes) for all conditions. Mean weighted skin and rectal temperatures, heart rate, total sweat produced and evaporated, and cardiac output, indirectly derived from blood pressure measurements, were the observed physiologic parameters. Evaluation of each parameter, individually, indicates that for some there is no relation between the physiologic response, the type of garment protection, and the level of thermal stress, while for others there is marginal benefit derived from wearing aluminized outer clothing. At only one time-intensity profile did the physiologic penalty of wearing nonreflective outer clothing appear more than marginal. However, even under the most severe conditions of thermal stress and absence of reflective protection, none of the physiologic responses approached tolerance limits in our terms of reference.

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